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AMBIENT NOISE SPECTRUM LEVELS AS A FUNCTION OF WATER DEPTH.(U)

JUN 69 A J PERRONE

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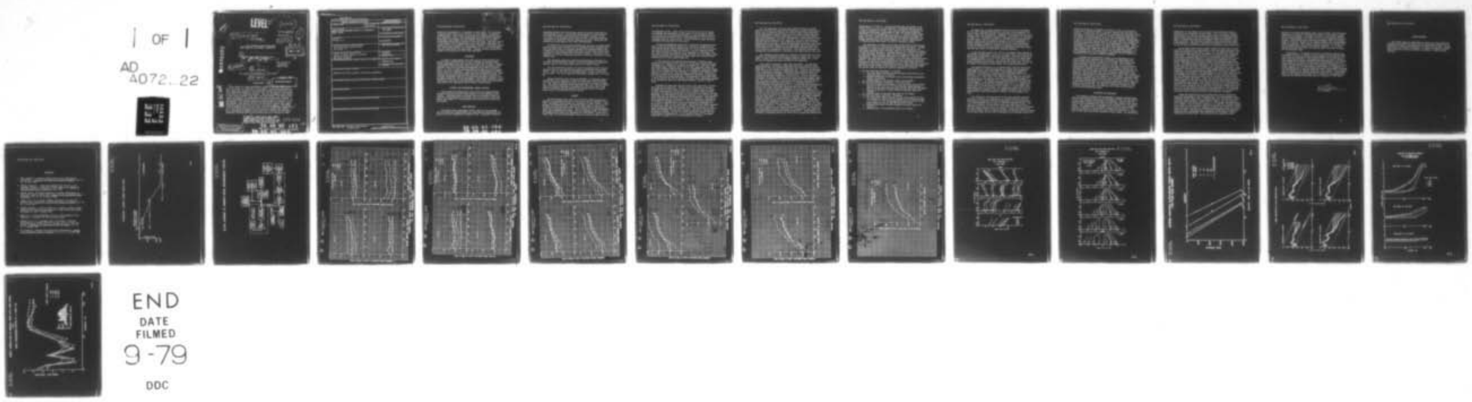

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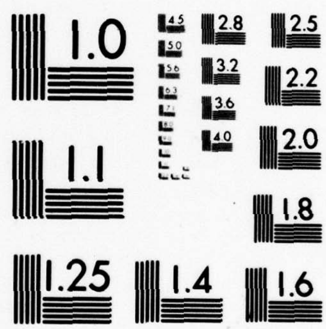

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(6) AMBIENT NOISE SPECTRUM LEVELS AS A
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INTRODUCTION

The results of recent measurements indicate that the level of ambient sea noise is a function of water depth. The results presented in this report were obtained from measurements gathered simultaneously from four hydrophones located in the open ocean, on the slope of a sea mount, in an area of the Northwest Atlantic. The four hydrophones were located in water depths of 400, 1100, 2400, and 2500 fathoms. The ambient noise levels are compared to simultaneous wind speed measurements recorded from an anemometer system located on a fixed platform in the area of the hydrophones. The data was obtained during the month of January. Broad band ambient noise levels from the four hydrophone outputs were simultaneously sampled every two hours for a two minute period. An average value of ambient noise in logit filter bands of frequencies ranging from 11 to 1414 Hz was estimated for each two minute sample. The results show a dependence of ambient noise levels as a function of water depth, frequency, and wind speed. The spectrum slope as a function of water

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depth is also observed to be dependent on wind speed. The variations in ambient noise levels as a function of depth produce a triangular shaped pattern. This pattern illustrates the changing spectrum slope as a function of depth. The changing spectrum slope and the ambient noise level depth dependence are probably caused by the two major directional noise sources existing in the open ocean. One noise source is sea surface, and is generated by local wind speed conditions; the second source is generated by long distant shipping. The surface generated noise signal arrives at the hydrophones at a more vertical angle than the long distant shipping signal. Distant shipping contributions arrive at the receiver via RSR and/or RRR paths.

BACKGROUND

A number of measurements have been reported which describe the ambient noise spectrum levels at many locations and various depths. Recent measurements have been reported by Wenz[1] and Perrone[2]. However, comparatively few measurements have been made where the ambient noise spectrum levels were recorded simultaneously as a function of water depth. In 1957, a series of measurements were made in the Tyrrhenian Sea by Lomask and Frassetto[3]. They measured the dependence of ambient noise levels as a function of depth using the Bathyscaph Trieste. More recently, simultaneous measurements were made by Arase and Arase[4] in the deep and shallow ocean on two identical hydrophones located in the Northwest Atlantic at 30 and 900 fathoms. The results presented in this report were also taken in the Northwest Atlantic where the measurements were made at four hydrophone depths during a 30-day period.

ACOUSTIC AND ENVIRONMENTAL SENSOR LOCATION

The acoustic measurements were made using four omnidirectional hydrophones located in water depth ranging from 400 fathoms to 2500 fathoms. Wind-speed data was obtained from an anemometer system located on a fixed platform in the open ocean in the area of the hydrophones (See Figure 1.) The anemometer was placed 150 feet above the sea surface.

DATA RECORDING

The ambient noise measurement system, shown in block-diagram form in Figure (2), automatically and simultaneously recorded the outputs of the four hydrophones on magnetic tape. Two-minute records of broad-band ambient noise levels were taken at two-hour intervals for approximately 30 days. The recorder was operated at a tape speed of 15 inches per second, permitting twelve two-minute records, or one day's data, to be recorded on each reel of tape. Wind-speed data was recorded on an AN/UMQ-5A recorder anemometer system[5]. Wind-speed and ambient-noise measurements were taken simultaneously.

To ensure that the recorded ambient-noise data was not contaminated by strong local noise sources, such as biological noise, shipping, and other man-made noise, the incoming signals were monitored aurally and in addition, were passed through seven logit filters whose outputs were displayed on a multichannel hot-wire paper recorder. The records were monitored on-line and ultimately served as a guide for editing out contaminated data.

The recording system was calibrated frequently by inserting, in the place of the hydrophone signal, calibration signals at frequencies corresponding to the center frequencies of the logit filters.

For each hydrophone channel, the data processing system[6] computed the mean value of the ambient noise signal from fifteen 1-second rms levels. This was done for each 2-minute sample at each of the logit filter bands. The filter bands had frequencies ranging from 11 to 1414 Hz.

Records exhibiting high levels attributable to biological noise, identifiable local shipping, or other man-made noise were discarded. All other data was grouped according to wind speed to obtain the spectra. The single wind-speed value associated with each 2-minute ambient noise record was determined by averaging the wind speed over a time interval extending from approximately 12 minutes before the ambient noise record to 12 minutes after the record.

RESULTS

The mean ambient noise level for the 30-day period is given as a function of wind-speed for each of the filter bands in Figures (3A) to (3G). Hydrophone depth appears as a parameter in these figures. Independent of hydrophone depth, the ambient noise level in the 11 and 14 Hz bands for wind speeds in excess of 25 knots shows an increase in level with increasing wind speed. Below 25 knots, the wind-independent noise sources dominate the bands. For the frequency range 17 to 89 Hz, the ambient noise levels are independent of wind speed. In this frequency band, the non-wind-dependent noise is as high or higher than the wind-dependent noise. Above 112 Hz the ambient noise level becomes increasingly more dependent on wind speed. In the frequency range 11 to 89 Hz the level difference between the 400 and 2400 fathom sensors varies from a maximum value of approximately 14 dB at 14 Hz to a minimum value of 2 dB at 89 Hz. In this frequency range the level difference is independent of wind speed.

For the wind-dependent portion of the spectrum (frequencies from 112 to 1414 Hz) the ambient noise level difference between 400 and 2400 fathoms varies from a minimum value of 2 dB at 112 Hz to an average value of 10 dB at higher frequencies. In this frequency range the level difference is observed to be dependent on wind speed. The same effect is also observed in Figure (4) where the mean ambient noise levels are plotted as a function of water depth for 10 selected frequencies and at 6 wind-speed conditions.

A more detailed plot showing the dependence of ambient noise levels as a function of water depth for six wind-speed conditions with frequency as a parameter is presented as Figure (5). This plot shows the ambient noise spectrum levels at the four hydrophone depths of 400, 1100, 2400 and 2500 fathoms. At each hydrophone depth the average value of the ambient noise is plotted for 10 selected frequencies ranging from 11 to 1414 Hz. The dependence of ambient noise levels as a function of depth is shown for six wind-speed conditions ranging from 0 to 50 knots in 10-knot intervals. Data reported by Arase and Arase[4] at 22 Hz (circle) and 707 Hz (square) received from a hydrophone located at 30 fathoms are shown for wind-speed conditions between 10 and 50 knots.

Although the Arase data was not taken at the same time, the data was taken in the same area. The fit of the Arase data to the data presented here is quite good. Observation indicates that the levels of these data points are in line with the triangular shaped pattern produced. The overall results show that for the 11 Hz signal, the deep hydrophone at 2400 fathoms receives approximately 10 to 12 dB more noise level than does the shallower hydrophone at 400 fathoms. This difference in noise level as a function of depth is observed to decrease as the frequency increases up to 89 Hz. For the frequencies from 89 Hz to 177 Hz, the ambient noise levels are essentially independent of water depth. Above 177 Hz, the ambient noise levels are again dependent on water depth and the level of noise is observed to be less at the deeper hydrophones than the shallower ones. The difference in ambient noise level between 400 and 2400 fathoms is observed to increase as frequency increases. At 1414 Hz a level difference between 1100 and 2400 fathoms of approximately 4 dB is observed during 0 wind-speed conditions as opposed to an 8 dB difference at 50 knots.

For the frequencies and wind-speed conditions where the noise signal is received from long distant shipping, a maximum difference in noise level is observed between the 2400 and 2500 fathom hydrophones. For the frequencies received from the local surface during high wind-speed conditions, a minimum difference in level is observed between these two hydrophones. The small differences in level observed during high wind-speed conditions is as expected, since the noise signal is arriving from the vertical, and propagation losses to the two hydrophones would be the same. During low wind-speed conditions, the larger differences observed between the two hydrophones for the frequencies which arrive at the receivers via the RSR and/or RRR paths are most likely caused by propagation conditions. What specific difference in propagation characteristics is involved is not understood at this time.

The changing spectrum slope as a function of water depth is illustrated by the triangular shaped pattern shown in Figure (5). For any depth, a cross section of the triangle (measured between the 11 and the 1414 Hz signal) indicates the slope of the spectrum.

This slope is observed to vary with wind speed. At high wind-speed conditions, (50 knots), where the major noise source is being generated by the local surface conditions, the ambient noise spectrum slope close to the surface is essentially flat. However, the spectrum slope is observed to increase continually with increasing water depth. At the 2400 fathom hydrophone, a spectrum level change of 32 dB is observed between the frequencies 11 and 1414 Hz. At low wind-speed conditions, (0 knots), where the local surface sources no longer exist, and where now the major noise source is produced by long distant shipping, the spectrum slope at the surface has changed from what was an essentially flat spectrum at 50 knots, to a spectrum which has a level difference of approximately 24 dB. At the 2400 fathom hydrophone, the spectrum level differences have increased from 32 dB, observed during the 50 knot wind-speed condition, to 45 dB at 0 knots. The increase in spectrum slope from high to low wind-speed conditions is a result of the absence of signal from the local surface sources as well as the increased propagation losses at the higher frequencies occuring from the long distant directional noise sources. The higher frequency signals produced by the long distant directional noise sources are attenuated much faster than the lower frequency signals. This effect can be seen by comparing the level change for the 11 and the 1414 Hz signal during the 50 knot wind-speed condition as opposed to the 0 knot wind-speed condition. A level change of approximately 6 dB is observed at 11 Hz, whereas a 20 dB change is observed at 1414 Hz. A plot showing the average spectrum slope/decade as a function of water depth for four winds speed condition is shown as Figure (6). These results were obtained by averaging through the levels of each logit band between the frequencies 11 to 1414 Hz. Average spectrum slope per decade of frequency varies at a rate of approximately 1 dB/decade/1000 foot depth + 2 dB as a function of depth. This rule of thumb for estimating the average spectrum slope is applicable at high wind-speed conditions, (50 knots), for the frequencies 10 to 1 KHz. At low wind-speed conditions, (0 knots), where the spectrum slope as a function of depth is higher than the slope observed during high wind-speed conditions, the average spectrum slope per decade changes to a rate of approximately .75 dB/decade/1000 foot depth + 12 dB as a function of depth.

The difference in ambient noise level between 400 and 2400 fathoms is observed to vary as a function of frequency and wind speed. Minimum difference in levels between hydrophone depths are observed at low wind-speed conditions where the noise signal at all frequencies arrives via the RSR and/or RRR paths. Maximum differences in levels are observed at high wind-speed conditions where the noise signal arrives from near the vertical. These changing differences in levels as a function of frequency and wind speed are the result of the two major directional noise sources. One noise source is generated by local wind-speed conditions which arrive from near vertical angles;[7,8] the second noise source is generated by long distant shipping and arrives at near horizontal angles[7,8]. The latter signal arrives at the receiver via the RSR and/or RRR paths. The results shown in Figure (5) could be summarized as follows:

1. For low wind-speed conditions - (0 knots)
   a. The noise signal arrives via the RSR and/or RRR paths for the frequency range 11 to 1414 Hz.
   b. Minimum differences in ambient noise levels between hydrophone depths are observed.
   c. Maximum slope to the spectrum occurs at all depths.
2. For the mid wind-speed conditions - (10 to 20 knots)
   a. The noise signal is a composite of the two major noise sources between 177 and 1414 Hz. For the frequency range between 10 and 177 Hz the noise signal arrives via the RSR and/or RRR paths.
   b. Moderate differences in level between hydrophone depths are observed.
   c. Moderate slope to the spectrum occurs at all depths.
3. For high wind-speed conditions - (50 knots)
   a. The major noise signal arrives from the near vertical for the 11 Hz signal as well as for the signals in the frequency range 177 to 1414 Hz. For the frequencies between 22 and 177 Hz the noise signal arrives via the RSR and/or RRR paths.
   b. Maximum differences in levels between hydrophone depths are observed.
   c. Minimum slope to the spectrum occurs at all depths.

In Figure (7), the mean spectrum level for the four hydrophones of 400, 1100, 2400 and 2500 fathoms is plotted versus frequency for each of eight wind-speed groups. Knudsen curves corresponding to sea states 0 and 6 are included for comparison. As noted in the discussion of Figure (5), the spectrum slopes are observed to vary as a function of water depth. The noise spectrum at the 400 fathom hydrophone exhibits a much flatter spectrum as opposed to deeper hydrophones. A gradual increase in spectrum slope is noted with increasing depths. At all hydrophone depths the distinction remains clear between that portion of the noise spectrum which is predominately wind-speed dependent and that which is long distant shipping dependent.

In the frequency range 17 to 112 Hz, the ambient noise spectra is independent of wind speed. Below the 17 Hz and above 112 Hz the noise spectra are predominantly wind-speed dependent. The noise spectras in the frequency range 17 to 112 Hz are characterized by two broad peaks at approximately 20 and 60 Hz. The latter peak (60 Hz) is most probably associated with distant shipping and the former peak (20 Hz) may be linked to biological sources and/or long range shipping noise.

The standard deviation of the ambient-noise data for three wind-speed groups (i.e., data corresponding to records whose associated wind-speed values fall within those three ranges) are plotted in Figure (8) as a function of frequency with hydrophone depth as a parameter. The three wind-speed ranges selected were 2.5 - 7.5, 12.5 - 22.5, and 37.5 - 52.5 knots. The overall results show that the standard deviation of the ambient noise data is weakly proportional to hydrophone depth. In addition, the standard deviations are dependent on wind speed. In the lowest wind-speed range (2.5 - 7.5 knots), the standard deviation varies from approximately 1 dB in the lowest frequency band to a peak value of 6 dB at 1000 Hz. In the middle wind-speed range (12.5 - 22.5 knots), the standard deviation curve has the same qualitative behavior as that of lowest wind-speed data, but its maximum value, which also occurs at 1000 Hz, is only slightly over 3 dB.

The variance in the mean values of the sound pressure spectrum levels as a function of frequency at wind speeds below 25 knots is interpreted as resulting from the superposition of two noise sources: (1) a wind-dependent source and (2) a non-wind-dependent source. The part of the variance in the ambient noise data attributed to wind-dependent sources is believed to be quite small and relatively invariant over the entire frequency range of interest. This would account for the small constant standard deviations that are found at high wind speeds. On the other hand, the part due to shipping is not constant, and at any particular frequency it depends on the amount, type, and location of ocean traffic and consequently, the noise received may have high variability. Furthermore, that variability increases with frequency, since the greater attenuation of noise in the upper frequency bands limits the extent of the geographical area in which contributing sources may be present, and hence, the total number of such sources. Qualitatively, it may be said that shipping noise in the lower bands that reaches the receiving hydrophones results from the superposition of noise fields associated with a large number of widely distributed sources. The contributions of these sources to the total noise field are relatively less dependent upon range and location of the individual sources. At higher frequencies, the noise field at the receiving hydrophones is more dependent upon local propagation conditions and the location of relatively fewer sources at shorter distances.

To provide some quantitative measure of the dependence of the total ambient noise spectrum upon fluctuations in wind speed, the ambient noise time series in each of the 25 logit filter bands were cross-correlated with the wind-speed time series. The resulting cross-correlation coefficients (at zero time lag) for the four hydrophone depths are plotted as a function of frequency in Figure (9). A histogram is included, which indicates the wind-speed distribution for the 30-day period for which the cross-correlation coefficients were computed. The results show that the correlation coefficient of wind-speed with ambient noise is independent of water depth. The coefficients are seen to be highest in the lowest and in the highest frequency bands, as would be expected from the spectra results shown in Figure (7). In the middle frequency bands, (17 to 112 Hz), where the noise is apparently generated by shipping, the correlation coefficients are not influenced in any orderly way. The value of correlation obtained in this frequency range will vary as a function of the noise level produced by the non-wind-dependent source.

DISCUSSION AND CONCLUSION

The results of ambient noise measurements recorded simultaneously from four hydrophones located in the Northwest Atlantic at water depths of 400, 1100, 2400 and 2500 fathoms are presented. The data was obtained during a 30-day period where the broad band ambient noise levels from the four hydrophones were sampled every two hours for a two-minute period. The results show a dependence in the ambient noise spectrum levels as a function of water depth, frequency and wind speed. The standard deviation of the ambient noise signal is observed to be dependent on wind speed and weakly dependent on water depth. The correlation coefficient of the ambient noise spectrum levels with wind speed is observed to be independent of water depth. The variations in ambient noise levels as a function of water depth produce a triangular shaped pattern which shows an increasing spectrum slope with increasing water depth. The spectrum slope as a function of depth is observed to vary with wind speed. The difference in ambient noise level between hydrophone depths as a function of frequency is suspected to be the result of the two major directional noise sources existing in deep ocean areas.

One of these noise sources yields a signal arriving from a nearly vertical direction and is generated by local wind-speed conditions which affect the frequency range above 177 Hz. In this frequency range, the ambient noise spectrum levels are observed to decrease with increasing water depth. This decrease in level as a function of depth becomes larger with increasing frequency. The other noise source yields a signal arriving from the horizontal direction and is generated by long distant shipping; this noise source affects the frequency range below 89 Hz. The ambient noise signals in this freuqency range arrive at the receiver via the RSR and/or RRR paths. The noise levels for this frequency range are observed to increase with increasing water depth. This increase in level as a function of depth becomes greater with decreasing frequency. In the middle frequency range (89 to 177 Hz) the ambient noise levels are observed to be independent of water depth; these results are probably caused by the combined effects of the two noise sources. The low frequency results presented are in agreement with the results reported by Arase and Arase[4]. Their data was obtained from two hydrophones located in the same area where the present measurements were made; one hydrophone was located at 30 fathoms and the other at 900 fathoms, both near the ocean bottom. The Arases' reported on an experiment which towed a source signal of 100 Hz just below the ocean surface, from ranges of 30 to 300 (nautical miles) from the hydrophones. They observed that the received level on the deeper hydrophone was on the average 14 dB greater than the received level on the shallower hydrophone.

Lomask and Frassetto[3] using the Bathyscaph Trieste conducted a series of experiments in the Tyrrhenian Sea. Their measurements were conducted at two diving sites - one near Capri, in over 1000 m of water; the other south of Ponza, in over 3000 m of water. At each site the dives were made during sea states 0 and 2. The diving time ranged from 3 to 9 hours. For sea state 0, Lomask et al. observed a constant ambient noise level over the frequency range 10 to 240 Hz as a function of water depth, and for sea state 2, a decreasing ambient noise level for increasing water depth. The decrease in level was observed for all frequency bands, but was considerably more pronounced for the higher frequency bands than the lower bands. For both sea state conditions, their results at the lower frequencies (below 132 Hz) differ from the results presented in this report, although the results for the higher frequencies are quite similar. The effects observed in the present studies at the low frequencies do not seem to exist in the Lomask and Frassetto results. Their results show wind-speed dependence over the frequency range 10 to 240 Hz, whereas in the present studies a non-wind-dependent source is observed. Their results indicate an absence of signal from the horizontal noise sources (long distant shipping). It is these sources which have been shown by Arase and Arase to greatly influence the low frequency range.

Consequently, in reviewing the Lomask and Frassetto results and the present results, it appears that the ambient noise spectrum levels could vary as a function of water depth dependent on the area and the types of sources existing. The suggestion then, is that for ambient noise signals which are predominantly wind-speed-dependent, the ambient noise levels as a function of water depth will decrease as depth increases and the spectrum slope will be essentially independent of water depth. However, if the total ambient noise signal is a composite of a wind-generated and a non-wind-generated signal (long distant shipping) then the variations in ambient noise level as a function of water depth will be similar to the results presented in this report. The spectrum slope of the ambient noise signal will increase with increasing water depth and the spectrum slope will vary as a function of wind speed.

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HYDROPHONE LOCATION VERSUS WATER DEPTH

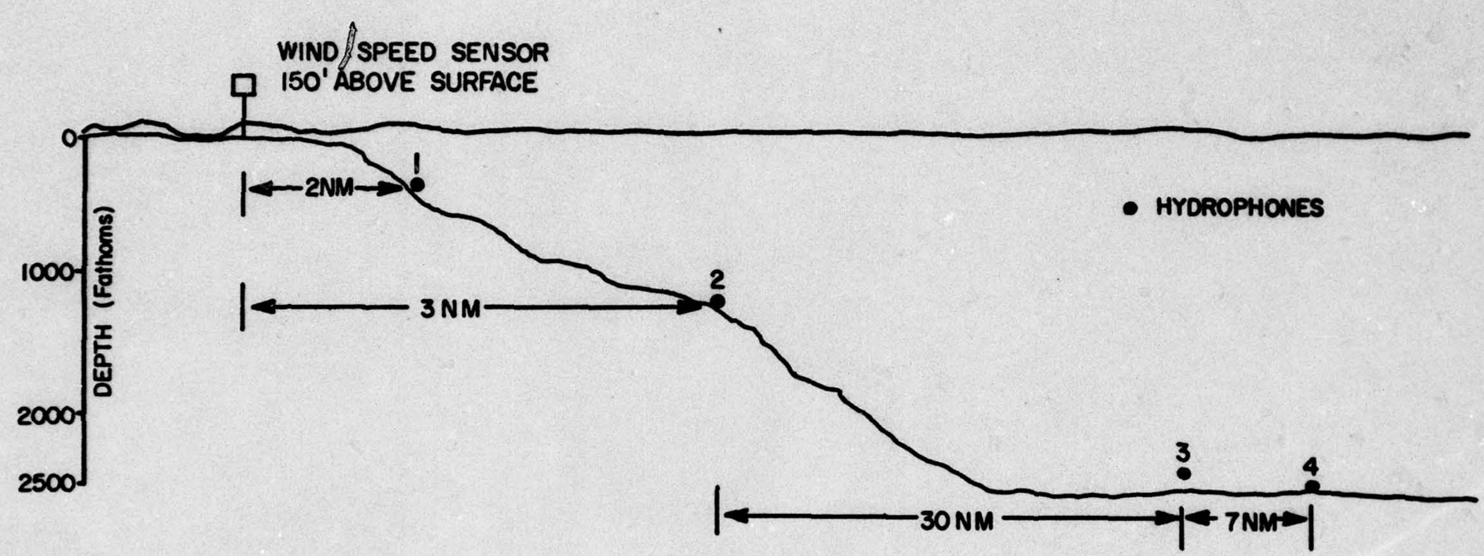


FIG. 1

BLOCK DIAGRAM OF AMBIENT-NOISE MEASUREMENT SYSTEM

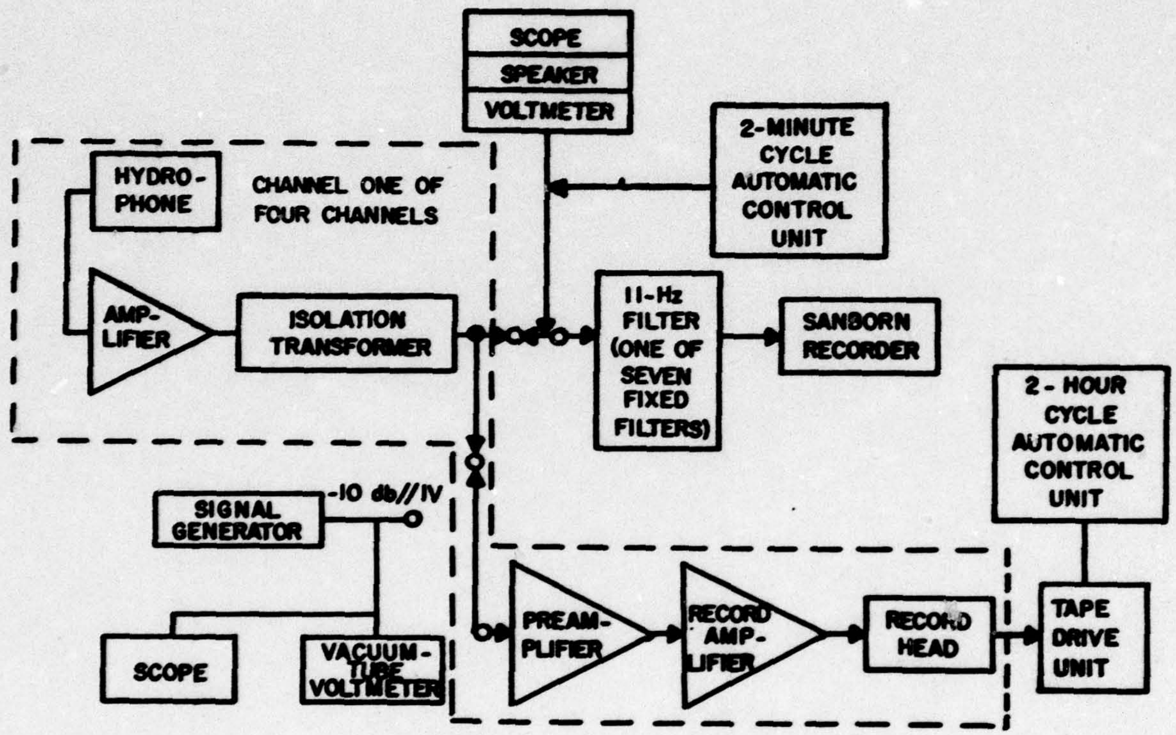
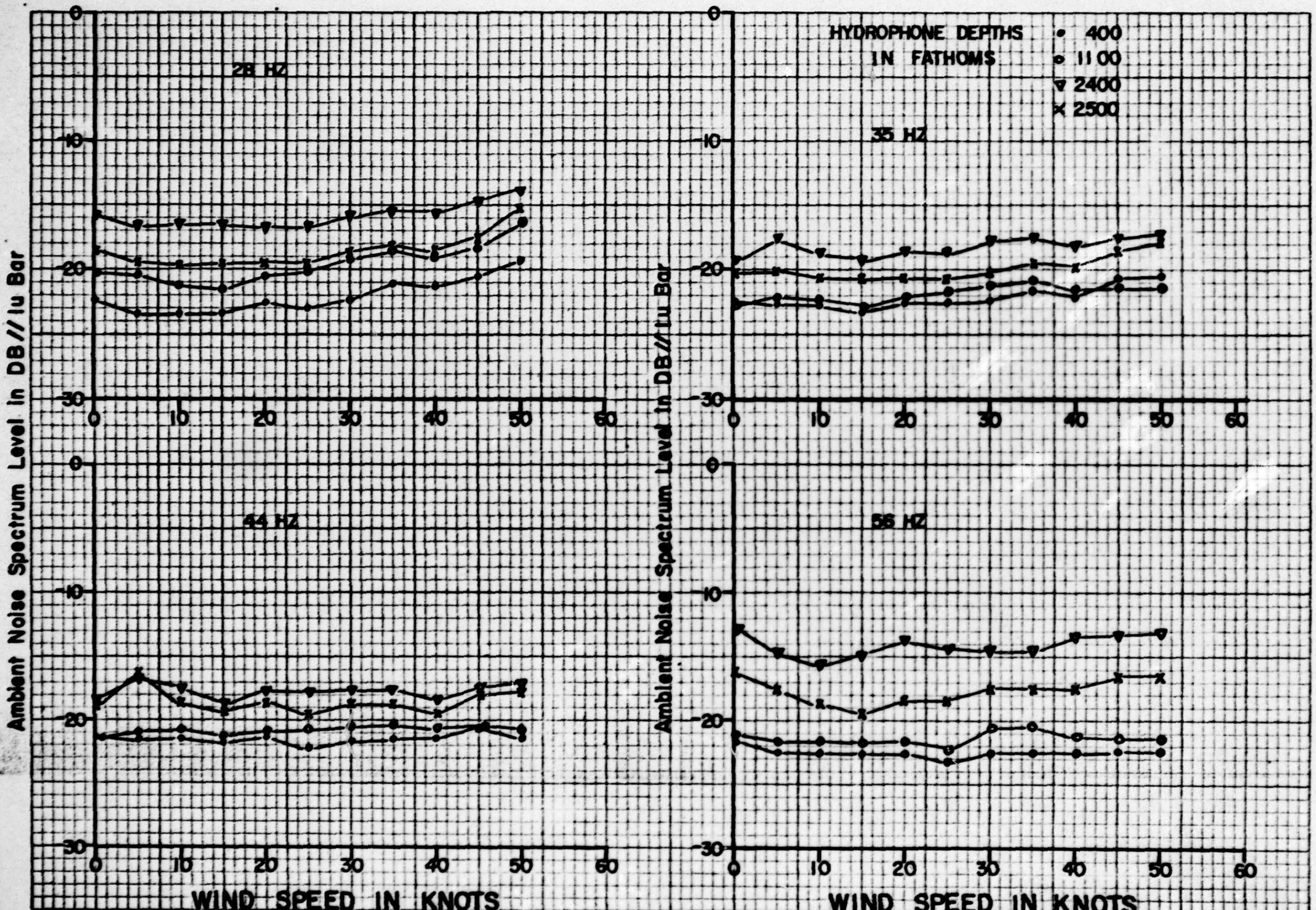
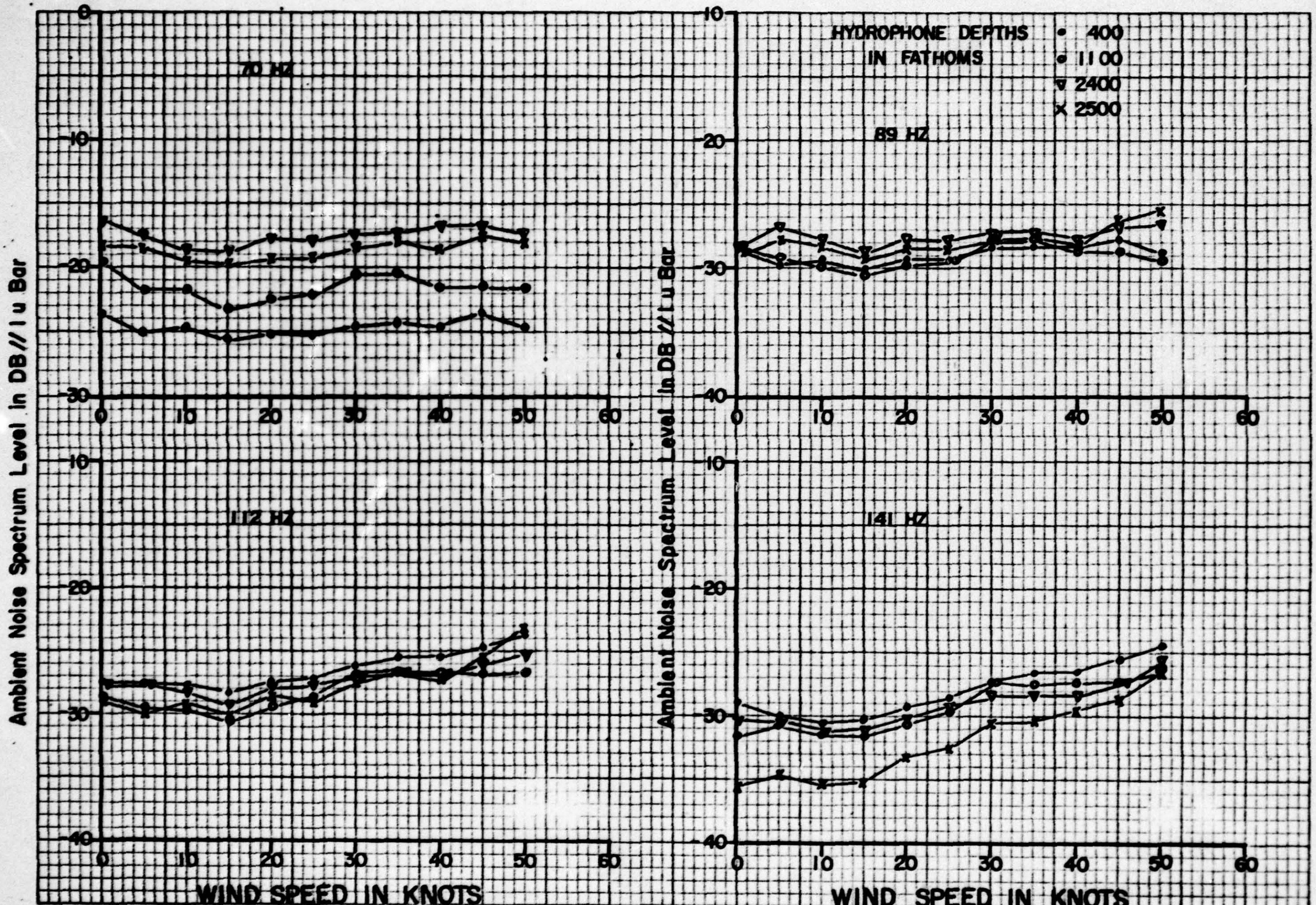


FIG. 2



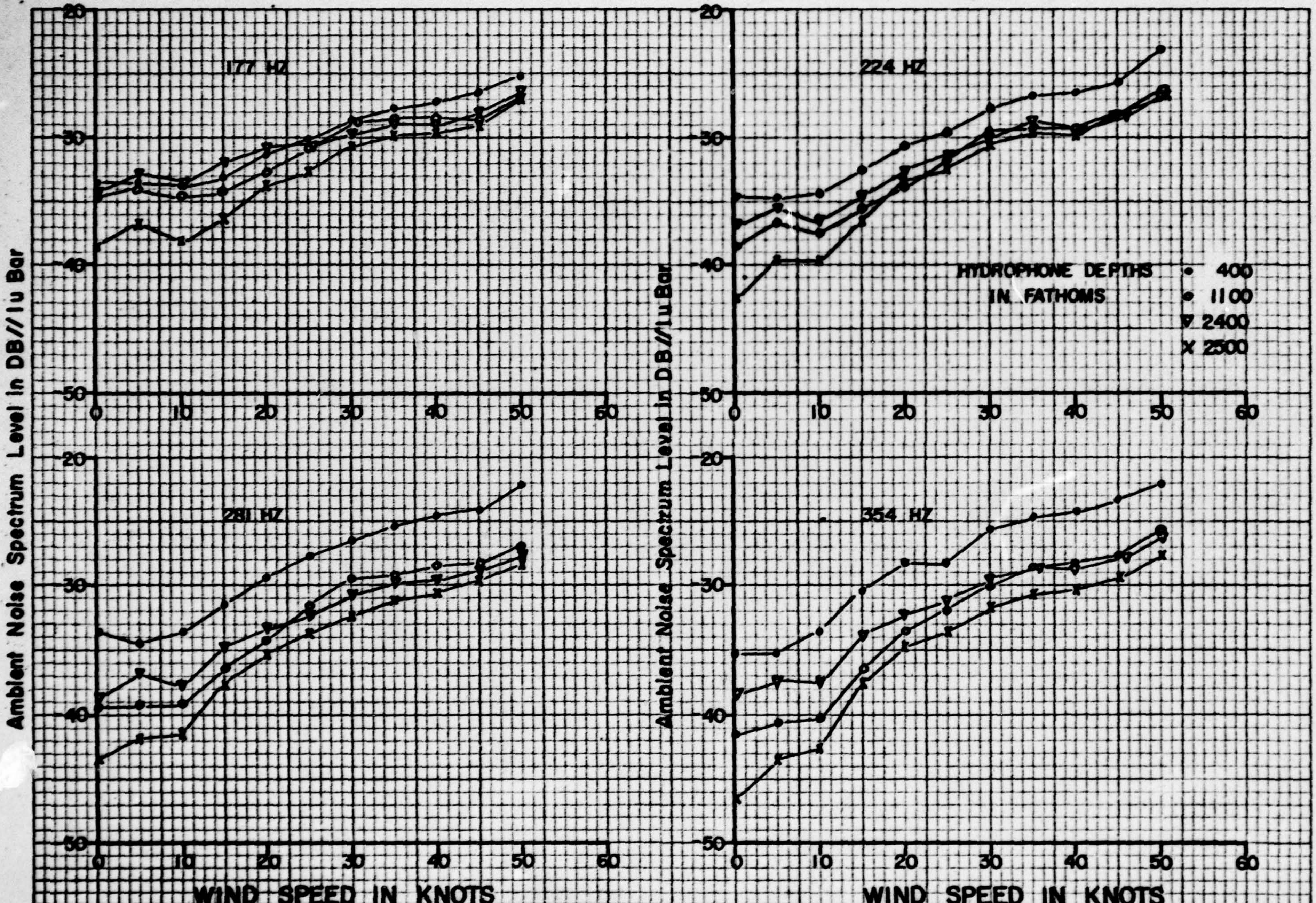
Ambient Noise Mean Spectrum Level Versus Wind Speed
At Four Hydrophone Depths

FIG. 3b



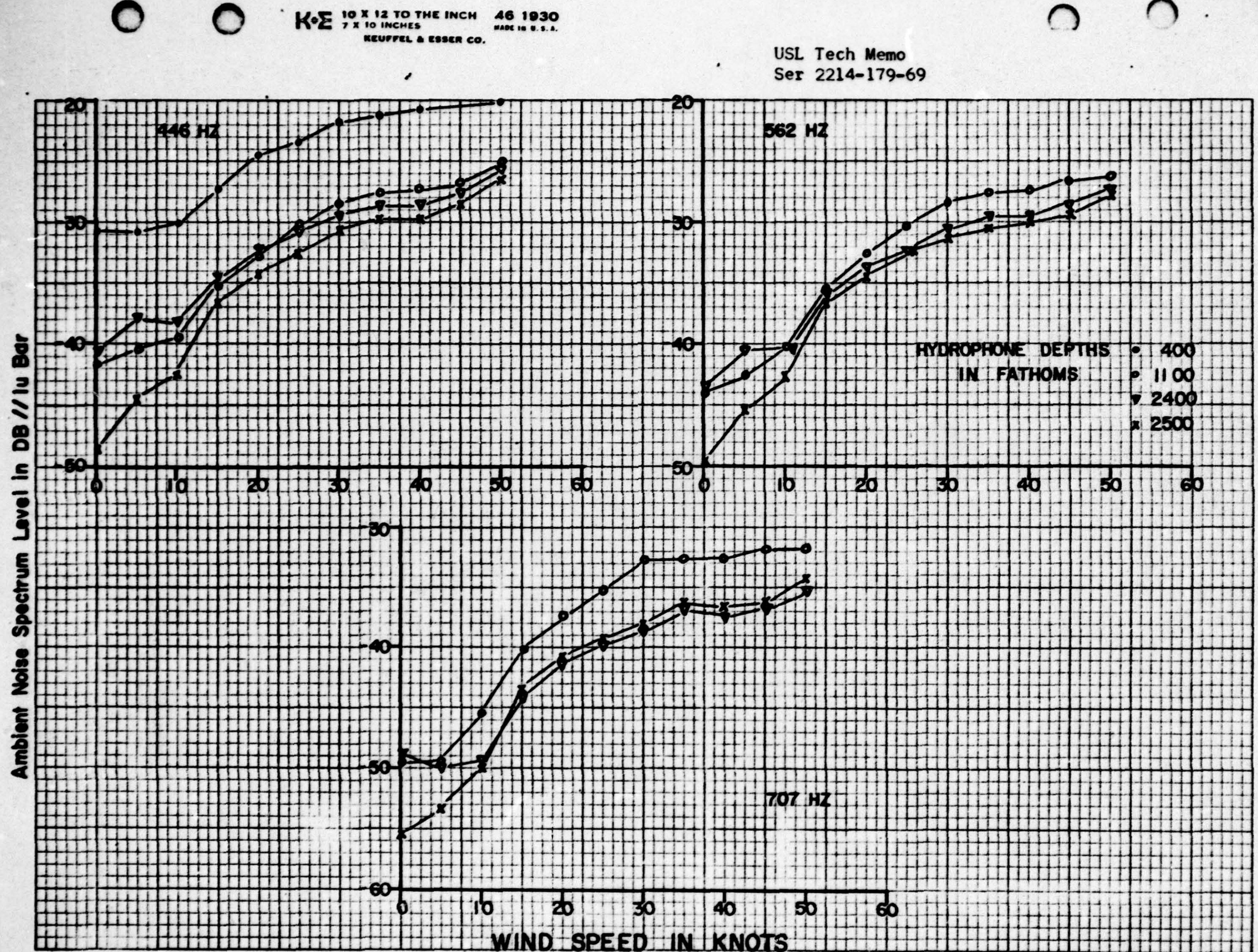
Ambient Noise Mean Spectrum Level Versus Wind Speed
At Four Hydrophone Depths

FIG. 3c



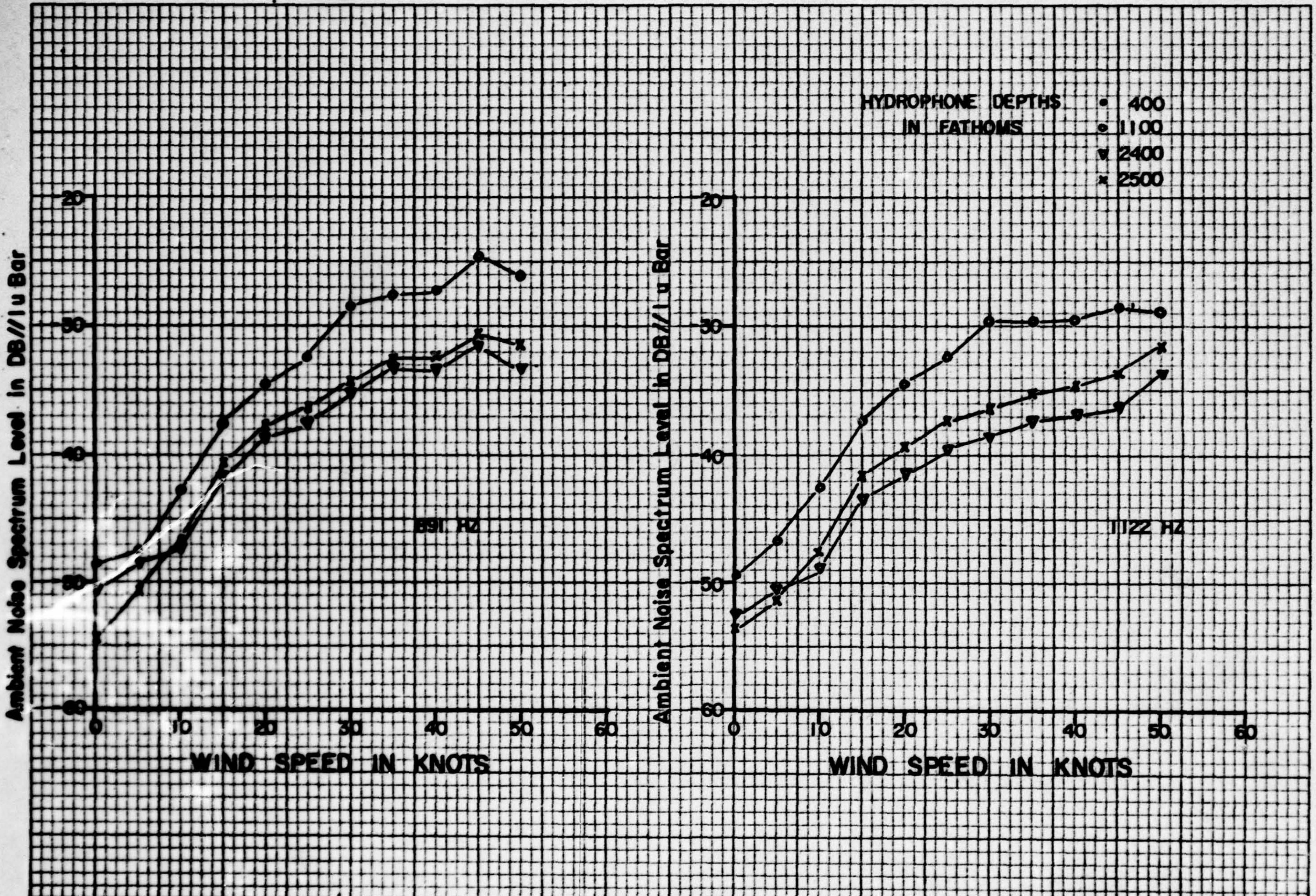
Ambient Noise Mean Spectrum Level Versus Wind Speed
At Four Hydrophone Depths

FIG. 3d



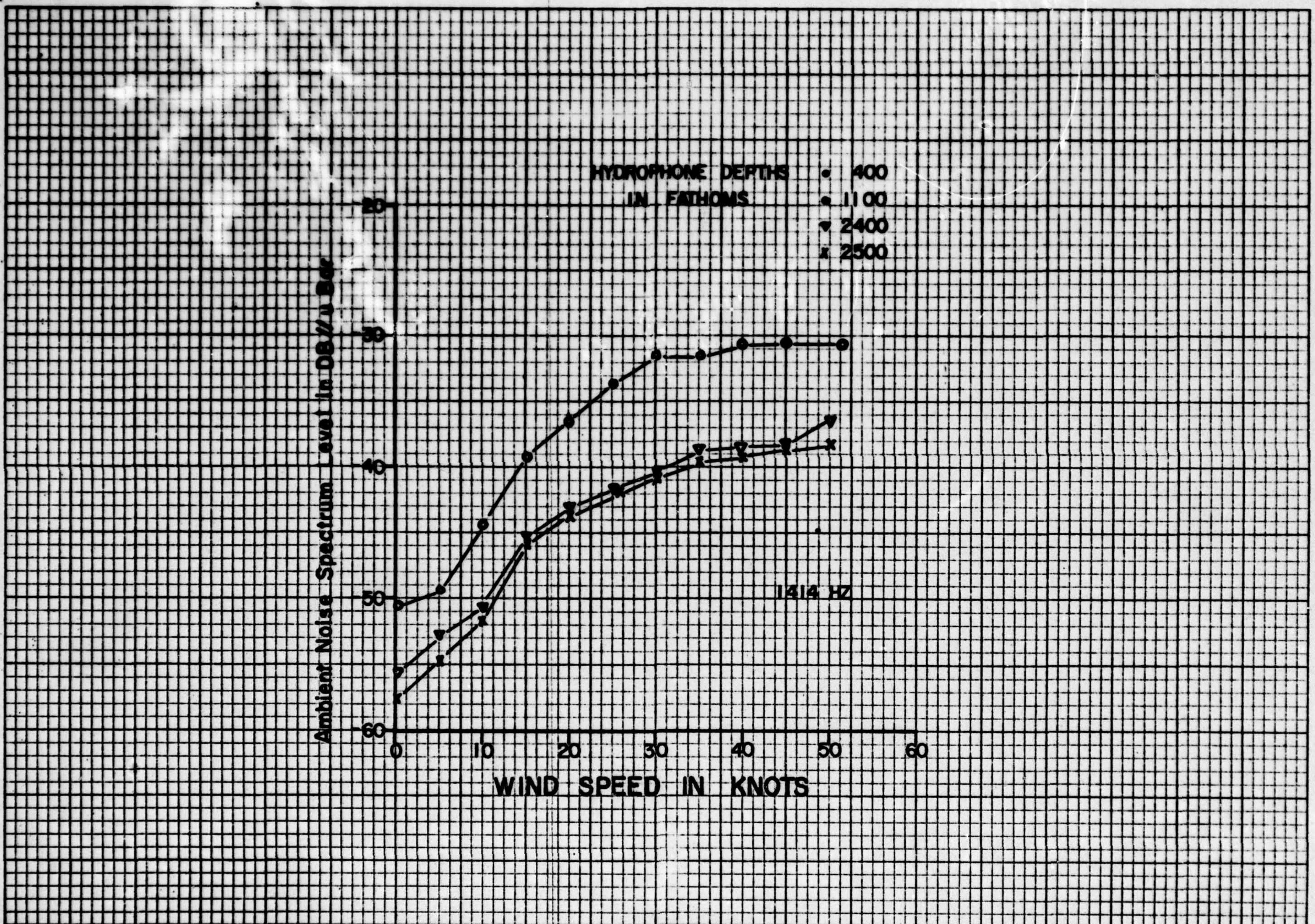
Ambient Noise Mean Spectrum Level Versus Wind Speed At Four Hydrophone Depths

FIG. 3e



Ambient Noise Mean Spectrum Level Versus Wind Speed At Four Hydrophone Depths

FIG. 3f



Ambient Noise Mean Spectrum Level Versus Wind Speed At Four Hydrophone Depths

FIG. 3g

AMBIENT NOISE LEVELS VERSUS WATER DEPTH

FOR 10 FREQUENCIES AT

6 WIND SPEEDS

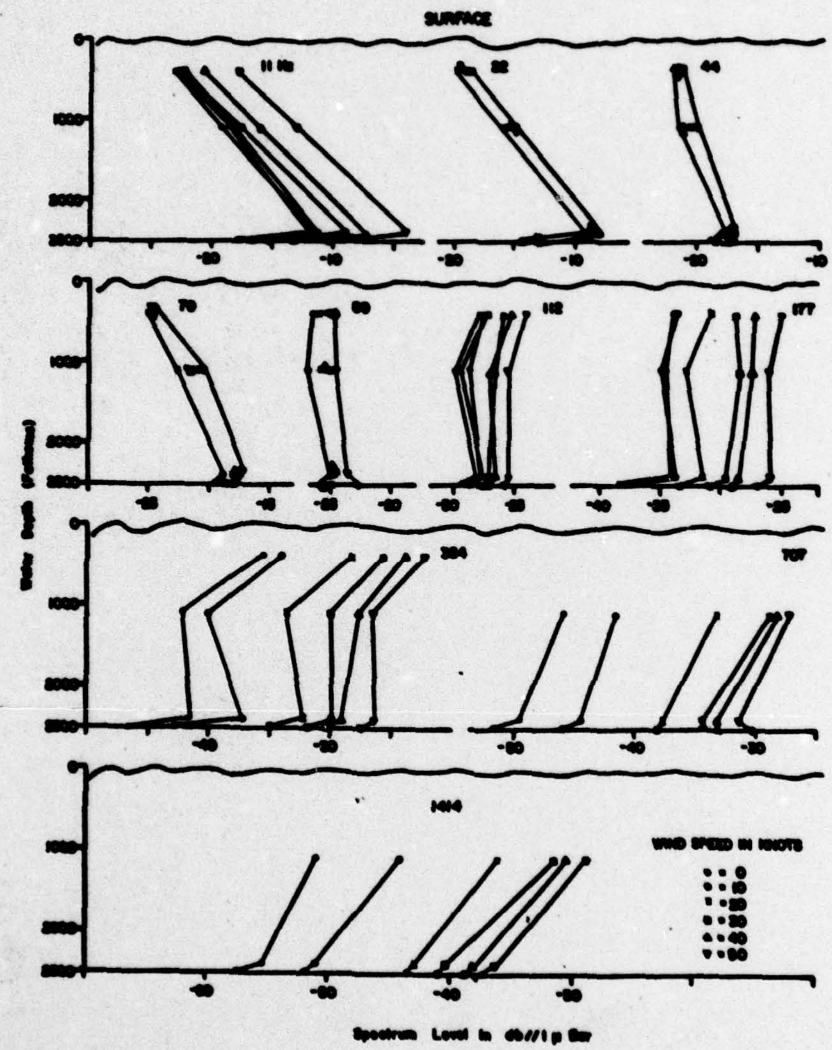


FIG. 4

AMBIENT NOISE LEVELS VERSUS WATER DEPTH
FOR 10 FREQUENCIES AT
6 WIND SPEEDS

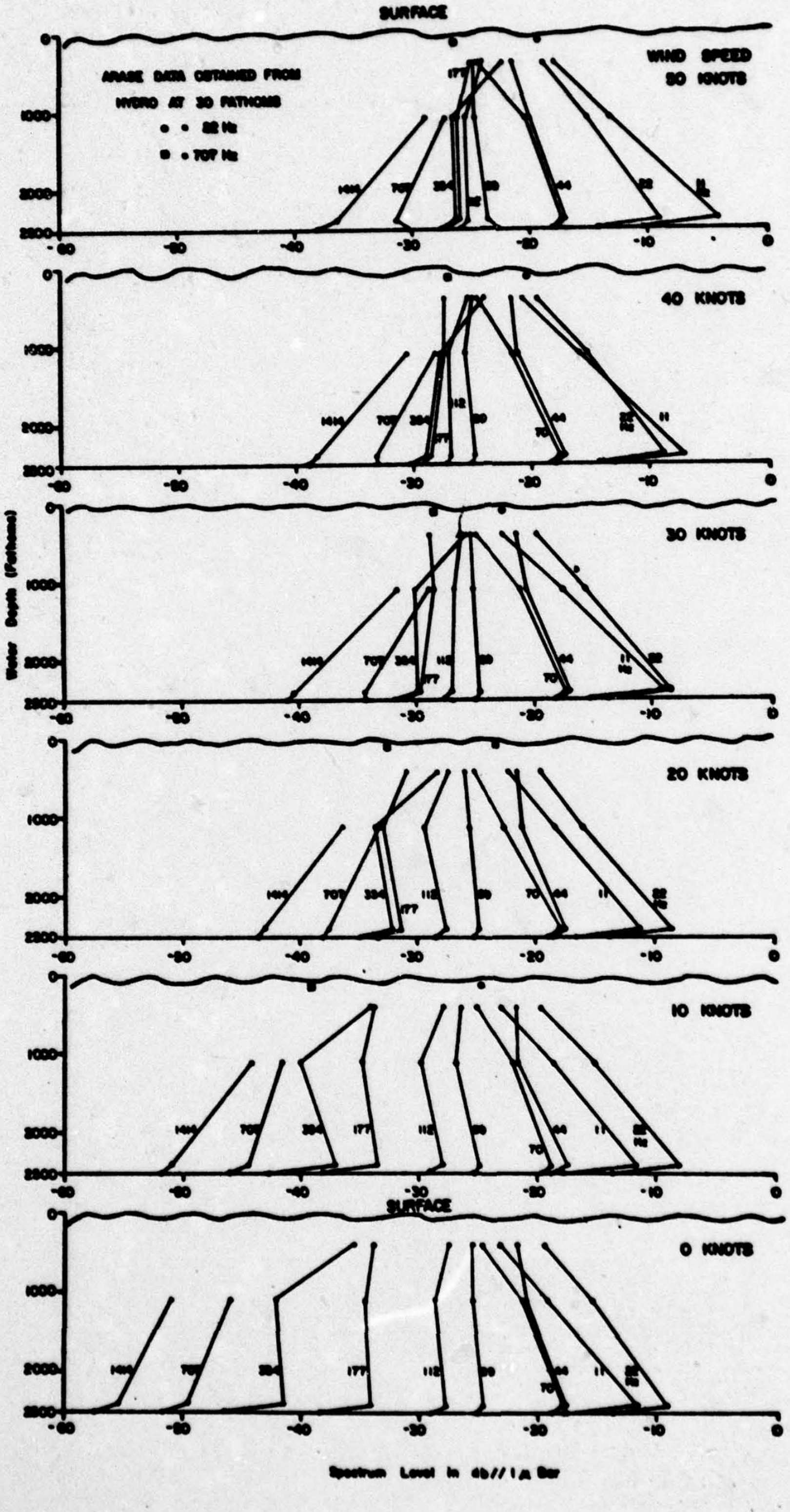


FIG. 5

AVERAGE SPECTRUM SLOPE/DECADE VERSUS WATER DEPTH FOR FOUR WIND SPEEDS

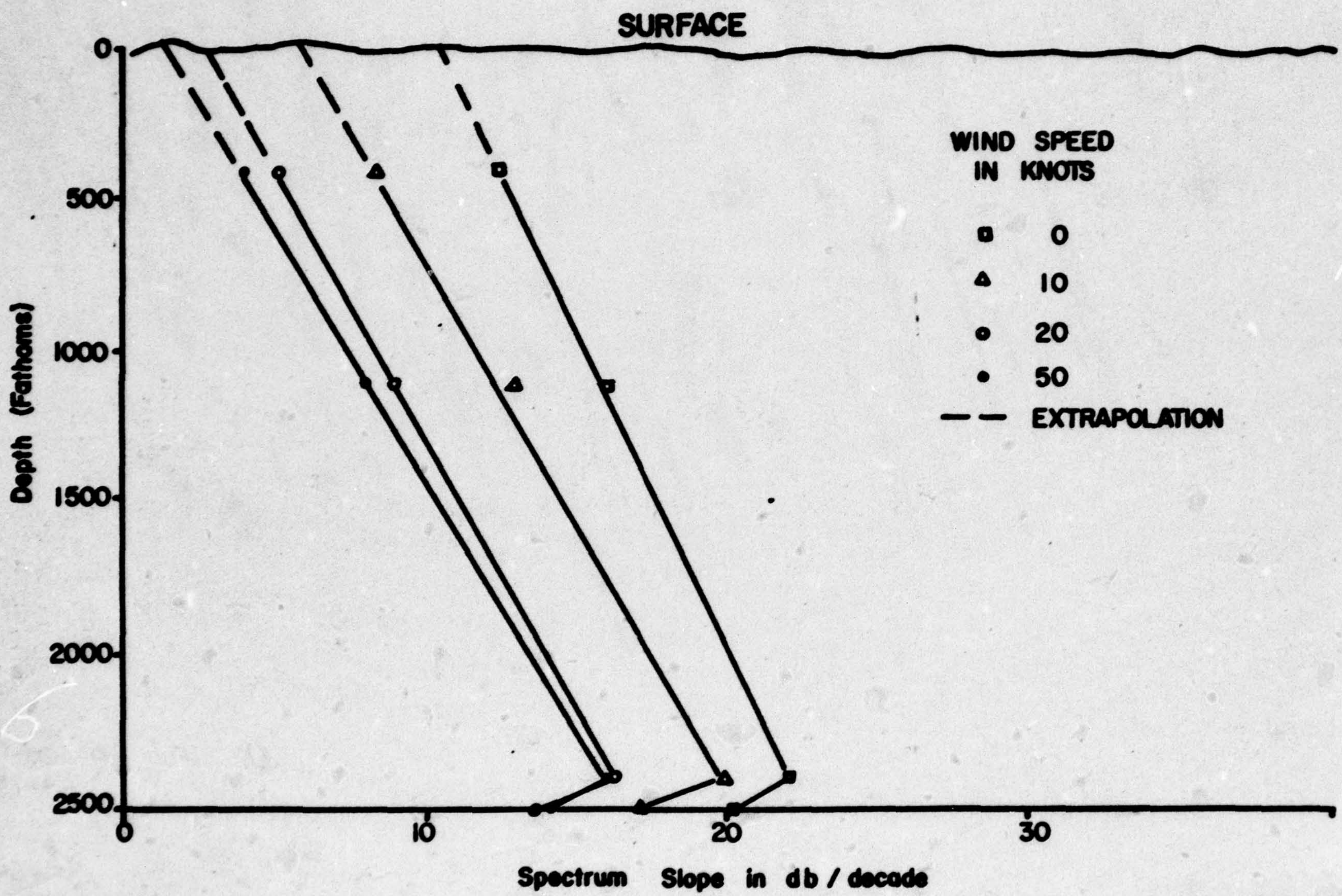


FIG. 6

AMBIENT NOISE SPECTRA AT FOUR HYDROPHONE DEPTHS

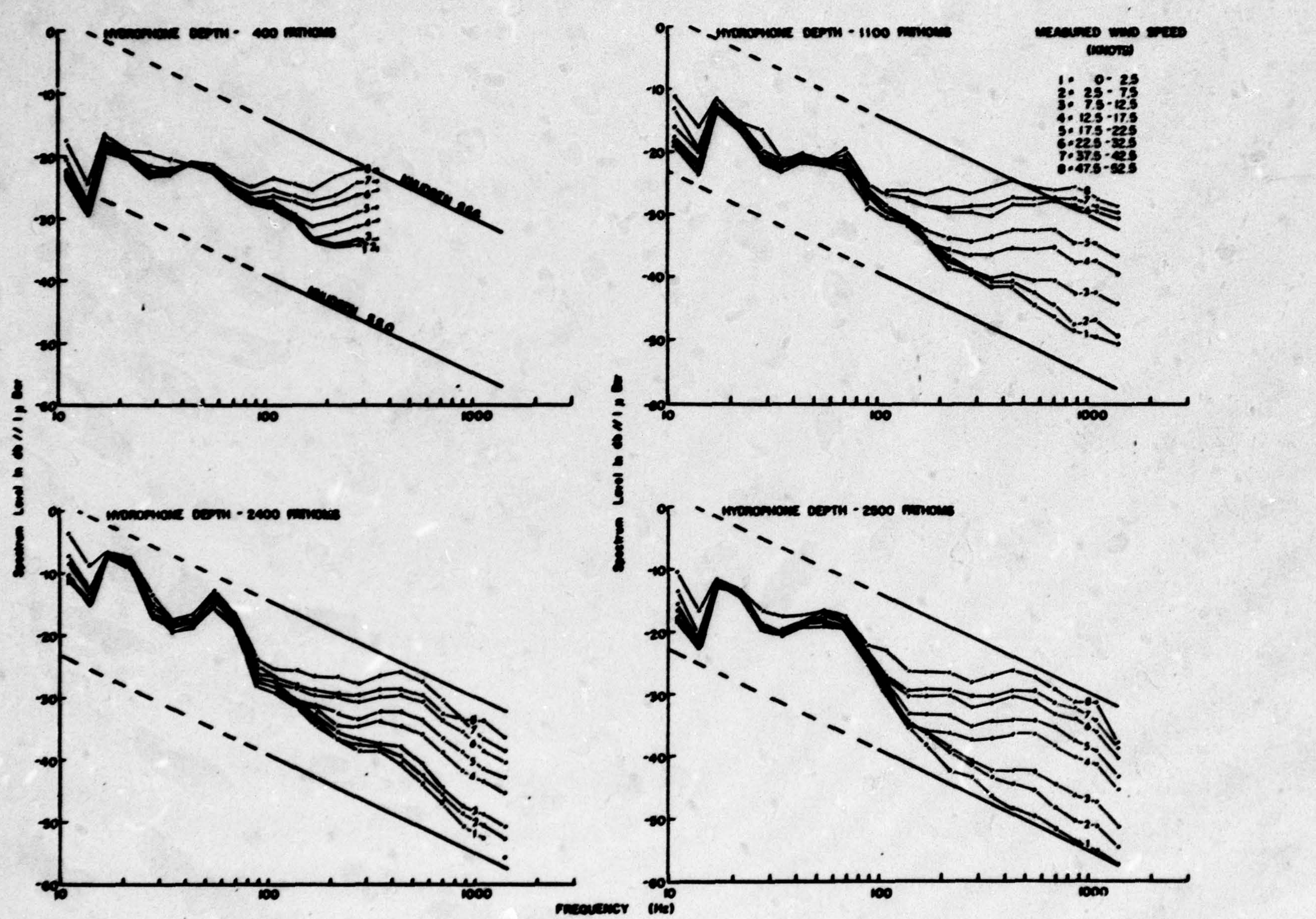


FIG. 7

STANDARD DEVIATION VERSUS FREQUENCY
FOR
FOUR HYDROPHONE DEPTHS
AT 3 WIND SPEEDS

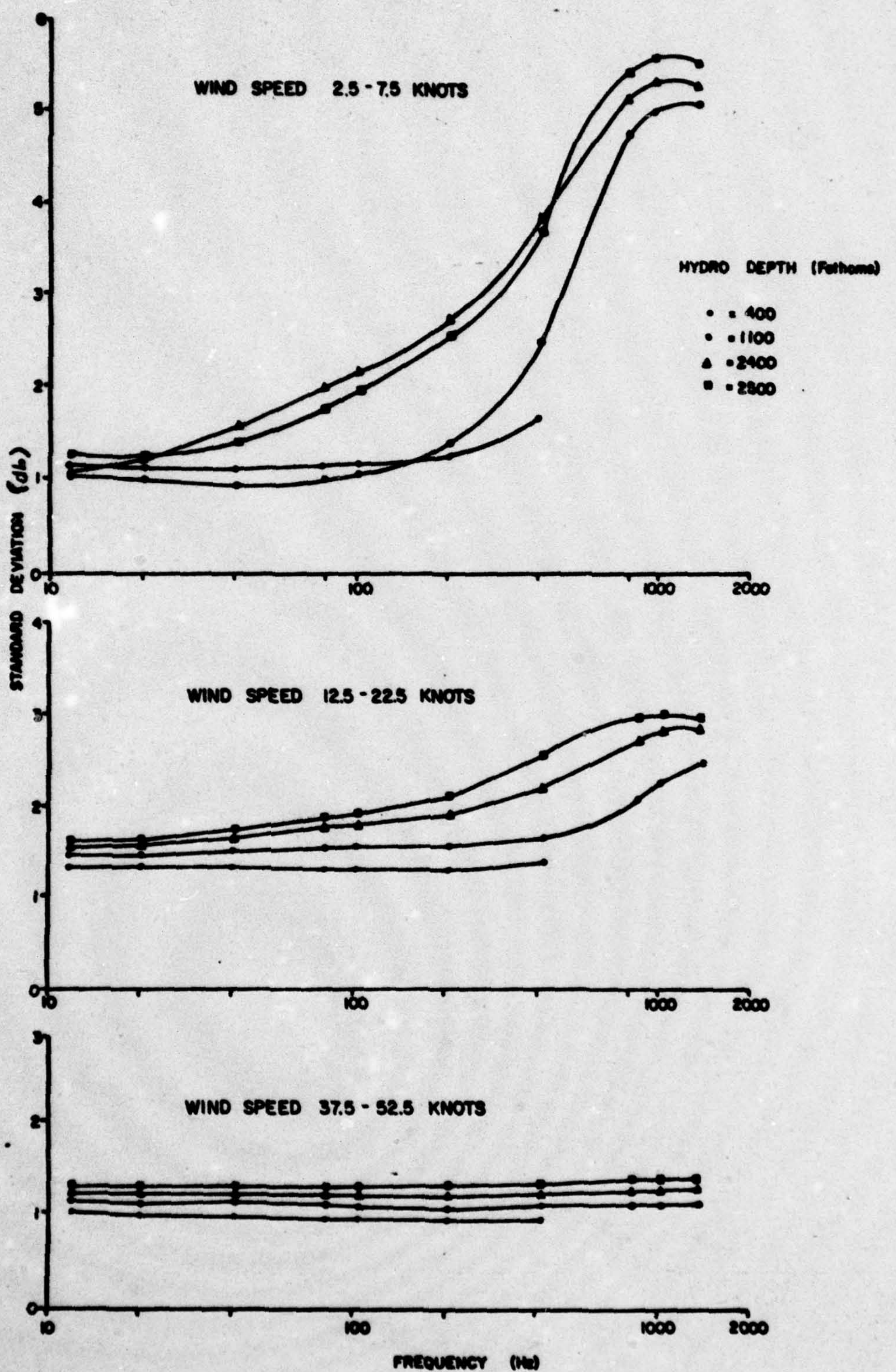


FIG. 8

CROSS CORRELATION OF AMBIENT NOISE WITH WIND SPEED
FOR
FOUR HYDROPHONE DEPTHS AT 0 TIME LAG

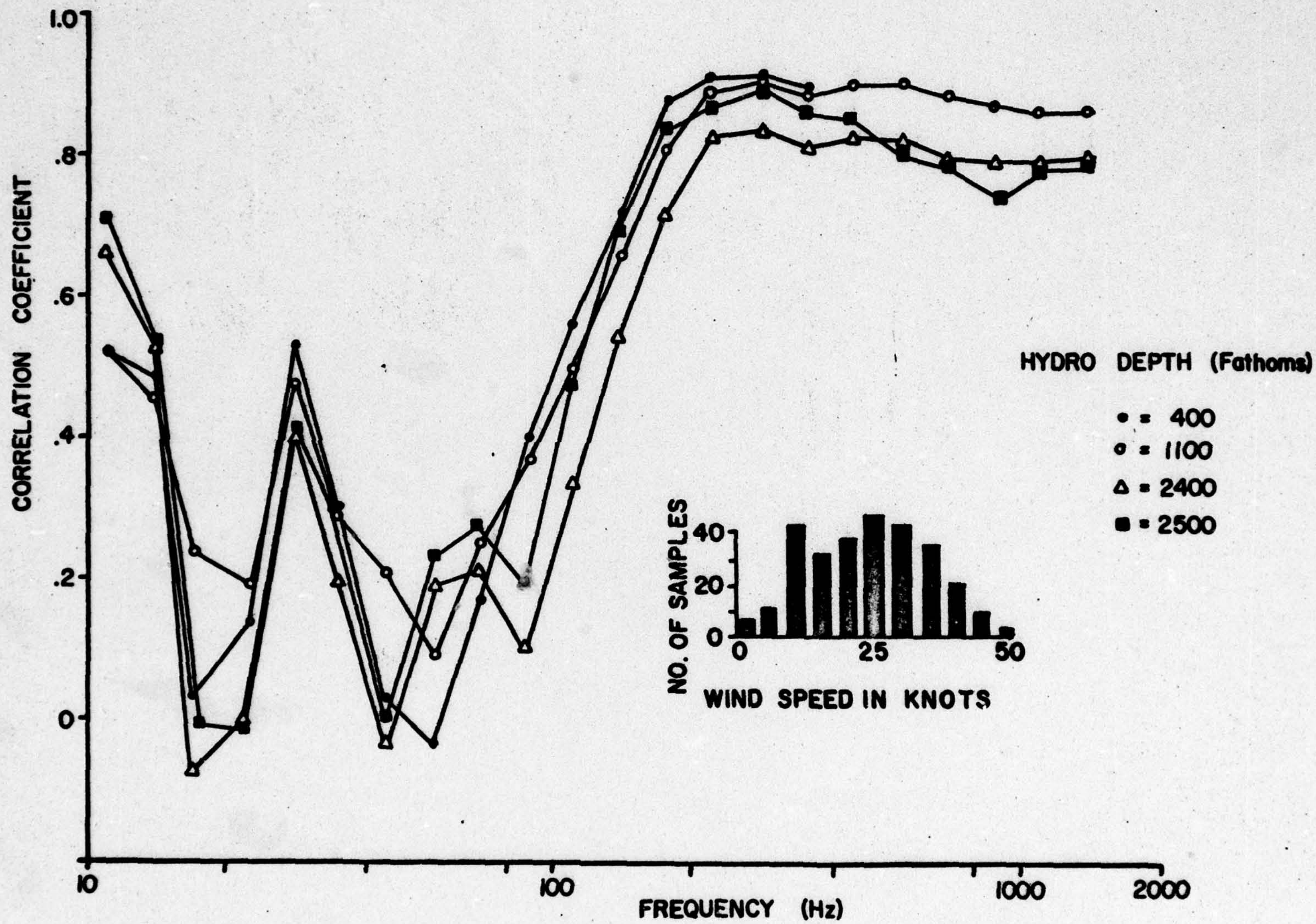


FIG. 9